OPTIMIZATION OF ELECTRICAL DISCHARGE MACHINE PARAMETER ON MILD STEEL BY USING RESPONSE SURFACE METHODOLOGY

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis deals with machining steel workpiece using Electrical Discharge Machining (EDM). The objective of this thesis is to determine the relationship between the machining parameters which is pulse-on time, pulse-off time, flushing pressure, peak current and servo voltage with material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). This thesis uses the response surface methodology techniques to turn out the equation the equation that use to optimize the MRR, EWR and SR and the fractional factorial design of experiment was used in the project. The machining of mild steel workpiece was performed by using an EDM machine ROBOFORM 200 and the analysis was done by using the MINITAB software. Based from the result, it is observed that the second order modal give more accurate prediction data for both MRR and EWR. The significant parameters that effect the EWR was the discharge current and discharge voltage. The EWR increased when this two parameter increase. The significant parameters are discharge voltage and pulse-on time for MRR. By previous researchers found that machining parameters had a large effect on geometric tool wear characteristics and machining performance outputs. Considering all of these parameters, a good machining condition can be obtained. This result also can significantly reduce the cost of operation and cost of product.

ABSTRAK

Tesis ini membincangkan proses pemesinan keluli kerja menggunakan proses pemesinan nyahcas elektrik (EDM). Objektif tesis ini adalah untuk menentukan hubungan antara parameter memesin yang digunakan iaitu, denyutan masa terbuka, denyutan masa tertutup, pembilasan tekanan, puncak arus dan servo voltan dengan kadar penyingkiran (MRR), nisbah kehausan elektrod (EWR) dan kekasaran permukaan (SR). Tesis ini menggunakan kaedah permukaan gerak balas untuk mengeluarkan persamaan persamaan yang digunakan bagi meramalkan MRR, EWR dan SR serta faktoran pecahan reka bentuk eksperimen telah digunakan dalam projek ini. Kerja pemesinan keluli ringan dilakukan dengan menggunakan mesin EDM ROBOFORM 200 dan analisis dibuat menggunakan perisian MINITAB. Daripada hasil, diperhatikan bahawa peringkat kedua modus memberi ramalan data yang lebih tepat untuk kedua-dua MRR dan EWR. Daripada keputusan, parameter penting yang member kesan kepada EWR adalah arus pelepasan dan voltan pelepasan. EWR meningkat apabila kedua-dua parameter ini meningkat. Untuk MRR, parameter yang penting adalah voltan pelepasan dan denyut pada masa. Daripada kajian yang telah dijalankan oleh penyelidik sebelum ini mendapati parameter pemesinan mempunyai kesan yang besar terhadap kerosakan alat dan prestasi pemesinan. Dengan mempertimbangkan kesemua parameter ini, kaedah pemesinan yang baik boleh dipersembahkan. Hasil ini juga boleh mengurangkan kos operasi dan kos produk.

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LIST OF SYMBOLS

t_i	Pulse On-time
t_o	Pulse Off-time
μs	The duration of time machining
μΩ	Electrical resistivity
s	second
W_b	Weight of workpiece material before machining (g)
W_a	Weight of workpiece material after machining (g)
A	Ampere
μm	Micrometer
$x_1, x_2, x_3, \ldots, x_k$	Input variables
α	Alpha phase
β	Beta phase
y	Response
ε	Error
η	Expected response
V	Voltage
I	Current

LIST OF ABBREVIATIONS

EDM	Electrical Discharge Machining
MRR	Material Removal Rate
EWR	Electrode Wear Ratio
SR	Surface Roughness
RSM	Response Surface Methodology
DOE	Design of Experiment
EWW	Weight of Electrode Use
WRW	Weight of Workpiece Used
ANOVA	Analysis of Variance
MS	Mean Square
D.O.F	Degree of Freedom
SS	Sum of Square
F	Fisher Test
P	Probability

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Since electrical discharge machining (EDM) was developed, much theoretical and experimental work has been done to identify the basic processes involved. It is now one of the main methods used in die production and has good accuracy and precision with no direct physical contact between the electrodes so that no mechanical stress is exerted on the work piece.

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The important output parameters of the process are the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). Optimization of the EDM process is concerned with maximizing MRR while minimizing EWR, and also producing the optimum SR usually, the finish should be as smooth as possible. This paper describes an investigation of EDM process optimization using response surface methodology (RSM) on mild steel material.

In 1979, Kruth et al. has developed an adaptive control system that optimizes settings on line, for example, servo reference voltage, pulse duration, pulse interval and dielectric flow rate. However, developed a new model reference adaptive control for EDM, which improved the machine stability and gave up to 40% higher machining productivity (Rajurkar et al. 1989)

1.2 IMPORTANT OF RESEARCH

The important of this research are:

1. Enhance the production rate.
2. Improve efficiency of production process.
3. Analyzing the effect and behaviors of mild steel in application die-sinking machine under various parameter machining.
4. Enhance the quality surface finish of the cut metal.

1.3 OBJECTIVE

There are some objectives of this research:

1. To optimize the cutting condition for maximum MRR, minimum EWR and better surface roughness using response surface methodology.
2. To establish mathematical models for some of the dependent variables by using RSM in a specific range of parameter.

1.4 PROBLEM STATEMENT

Wear will occur on the electrode during machining process. The efficiency of production process will be disturbed because of that. Otherwise, the characteristic condition of workpiece will be cracked during the process. Mild steel AISI 1020 is a soft material, thus a proper machining is required to avoid the crack.

1.5 PROJECT SCOPES

A research focus on machining parameter and methodology that effect to the result. There are several main scopes in this project are:

1. Make analysis by using Response Surface Methodology (RSM) in optimizing Electrical Discharge Machine (EDM) on mild steel workpiece.
2. The type of machine is Die-sinking Electrical Discharge Machine (EDM)
3. Design Of Experiment (DOE) methodology is applied to define the main parameters and relationship between parameters.
4. Copper is used as an electrode.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Electric discharge machining (EDM) is a widely used non-traditional machining process in the manufacture of complex shaped dies, molds and critical parts used in automobile, aerospace, surgical and other industrial applications. The process uses thermal energy of the spark to machine electrically conductive parts regardless of the hardness of the work material. This unique feature of EDM has a distinct advantage in the manufacture of complex shaped die and molds made up of hard materials which are difficult to machine by conventional machining processes (K.H. Ho and S.T. Newman, 2003). The EDM process has limitations such as longer lead times and lower productivity which restricts its application. Researchers worldwide are thus, focusing their attention on improving the productivity and finishing capability of the EDM process.

2.2 ELECTRICAL DISCHARGE MACHINE (EDM)

EDM has been an important manufacturing process for the tooling, mould and die industries for several decades. The process is finding an increasing industrial use due to the ability of producing geometrically complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. According to Sommer (2000) EDM can be categorized into two: die sink EDM and wire EDM. However, Pandey and Shah (1980) classified EDM processes into three main categories as shown in Figure 2.1.

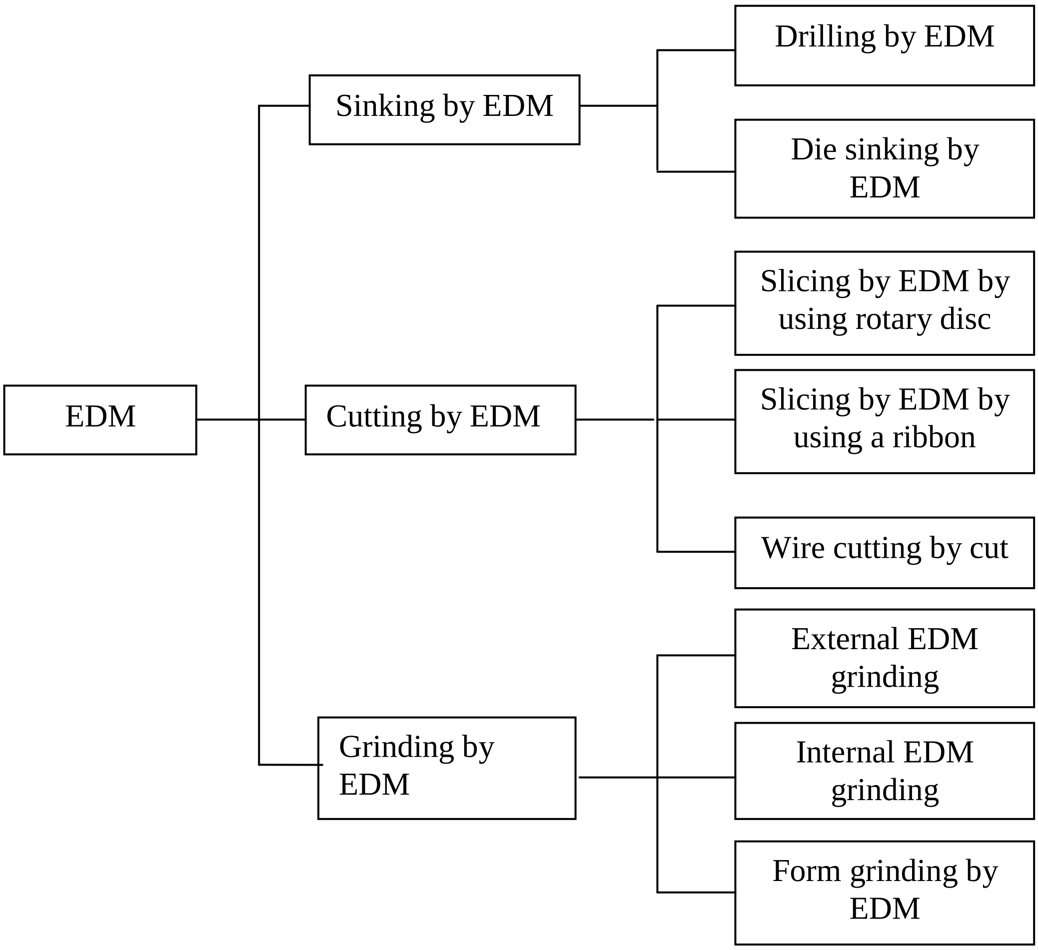

Figure 2.1: Classification of EDM processes

Conventional EDM, also known as sinker EDM, die sinker, vertical EDM, or plunge EDM is generally used to produce blind cavities (Sommer, 2000). When blind cavities are required, a formed electrode is machined to the desired shape. Then, by means of electrical current the preformed electrode surrounded by dielectric fluid, reproduced its shape in the workpiece. A powerful spark causes pitting or erosion of the metal on both the anode (+) and cathode (-). This process is also called spark machining or spark erosion machining. The EDM process involves a controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark discharges between the electrode and workpiece which is separated by a small gap.

EDM is known to have capability in producing small holes. It can be used for making nozzles, irregular holes and complicated shape and profiles, for embossing and engraving operations on hardened materials (Mahajan, 1981). The sinker EDM is best suited for machining deep and thin cavities in hard materials (Altan *et al*., 1993), the process, however, relatively slow when compared to milling operation. Much work in recent years has been devoted to orbital EDM, EDM milling, unattended and high speed EDM, use of non flammable dielectrics fluids, increasing machining accuracy, and the reduction and control of electrode wear (Abu Zeid, 1996, 1997; Yan and Wang, 1999; Lin *et.al*, 2000; Wang and Yan, 2000; Yan *et al*., 2000; Rozenek *et al*., 2001; and, Kaminski and Capuano, 2003). Ho and Newman (2003) have classified research areas in EDM machining process as shown in the Figure 2.2.

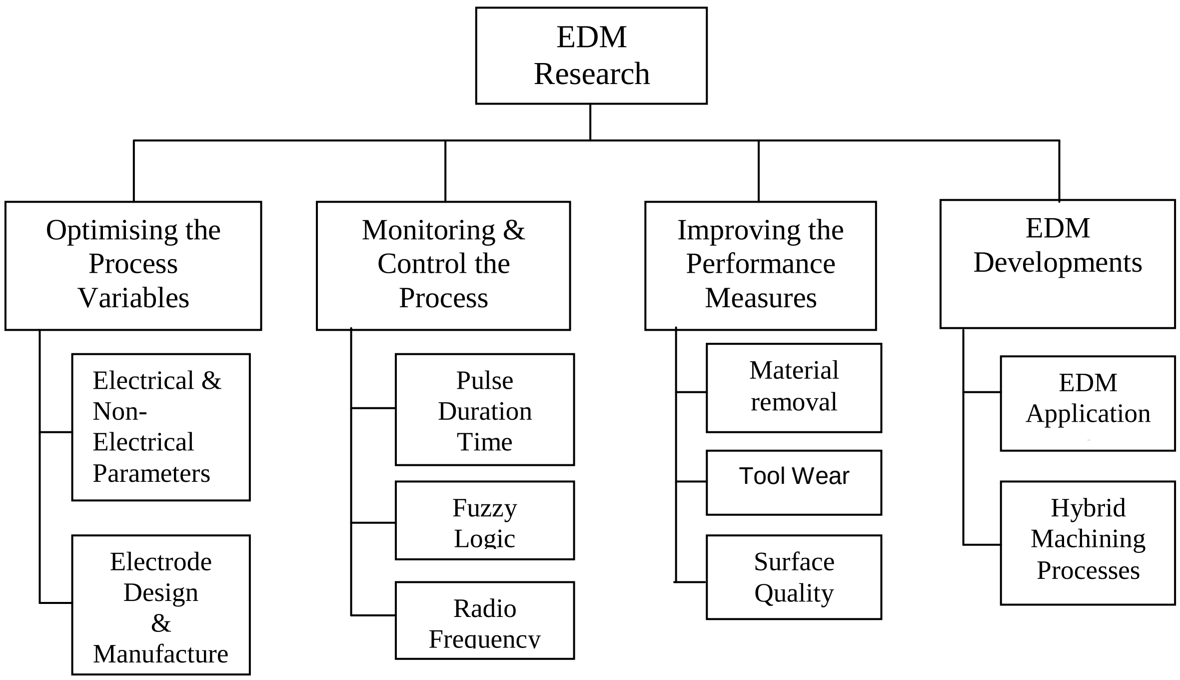

Figure 2.2: Classification of major EDM research areas

Source: Ho and Newman, 2003

2.3 DIE-SINKING EDM MACHINE

Die-sinking EDM machines are also known as ram or vertical EDMs. The equipment used to perform the experiments was a die-sinking EDM machine of type ONA DATIC D-2030-S. Also, a jet flushing system in order to assure the adequate flushing of the EDM process debris from the gap zone was employed. The dielectric fluid used for the EDM machine was a mineral oil (Oel-Held Dielektrikum IME 82) with a flash point of 82 ◦C. The electrodes used were made of electrolytic copper (with a cross-section of 12mm×8 mm) and the polarity was negative.

Die-sinking EDM has four sub-systems, that are:

1. DC power supply to provide the electrical discharges, with controls for voltage, current, duration, duty cycle, frequency, and polarity.
2. Dielectric system to introduce fluid into the voltage area/discharge zone and flush away work and electrode debris, this fluid is usually a hydrocarbon or silicone based oil.
3. Consumable electrode, usually of copper or graphite.
4. Servo system to control in feed of the electrode and provide gap maintenance.

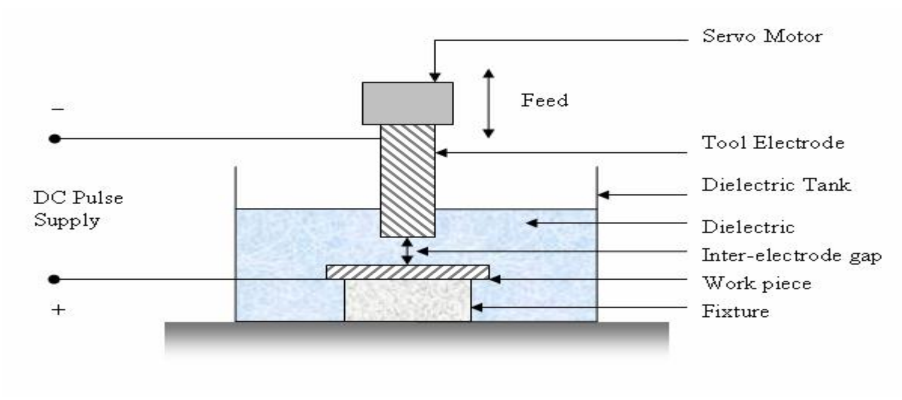

Figure 2.3: Schematic of an Electric Discharge Machining (EDM) machine tool

The schematic of an EDM machine tool is shown in Figure 2.3. The tool and the workpiece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the workpiece is generally provided for maintaining a constant gap distance between the tool and the workpiece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the workpiece, the tool is moved downward towards the workpiece to maintain a constant inter-electrode gap. The tool and the workpiece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap, (Sourabh Kumar Saha, 2008).

Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the workpiece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. The inter electrode gap is in the range of a few tens of micro meter to a few hundred micro meter. Material removal rates of up to 300 mm3/min can be achieved during EDM. The surface finish (Ra value) can be as high as 50 μm during rough machining and even less than 1 μm during finish machining, (Sourabh Kumar Saha, 2008).

2.4 MACHINING PARAMETERS

The machining performances depend on various EDM parameters (variables). Wang and Yan (1999, 2000) categorized the parameters into two groups;

1. Electrical Parameters:
   a. Polarity
   b. Peak current
   c. Pulse duration
   d. Power supply voltage

2. Non electrical parameters:
   a. Rotational of speed electrode
   b. Injection flushing pressure

In the other hand, Van Tri (2002) categorized the parameters into five groups:

1. Dielectric fluid; type of dielectric, temperature, pressure, flushing system
2. Machine characteristics; servo system and stability stiffness, thermal stability and accuracy.
3. Tool; material, shape, accuracy.
4. Workpiece
5. Adjustable parameters; discharge current, gap voltage, pulse duration, polarity, charge frequency, capacitance and tool materials.

However, previous researchers (Osycka *et al*., 1982; Singh *et al*., 1985; Madan and Sagar, 1994; Yan and Wang, 1999; Lin *et al*., 2000; Tsai and Wong, 2001; Liu, 2003; and, Tzeng and Chen, 2003) described that adjustable parameters are always considered as critical parameters. From the description above, the electrical parameters are more significant than non-electrical parameters on the machining characteristics (Singh *et al*., 1985; Abu zeid, 1997; Wang and Yan, 2000; Marafona and Wykes, 2000 ; Van Tri, 2002; and, George *et al*., 2003).

Although the non-electrical parameters are less significant as compared to electrical parameters, many researchers had focused on this area. Erden (1982) reported that dielectric flushing affected the EDM performance due to the changing of erosion rate, mirror like finishing achieved by multi divided electrode method (Mohri and Saito, 1985). Yan and Wang (1999) investigated the effect of rotary tube electrode on machining characteristics of Al2O3/6061Al composite. Improved jet flushing for EDM was investigated by Masuzawa *et al*. (1992). They found that the distribution phenomenon of debris had a good correlation with the geometry of the workpiece surface produced.

2.5 EDM PROCESS PARAMETERS

2.5.1 Discharge voltage

Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric (Kansal et al., 2005). Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and workpiece. Higher voltage settings increase the gap, which improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases. However, the impact of changing open circuit voltage on surface hardness after machining has been found to be only marginal.

2.5.2 Peak Current

This is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. In both die-sinking and wire-EDM applications, the maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but at the cost of surface finish and tool wear. This is all more important in EDM because the machined cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining. New improved electrode materials, especially graphite, can work on high currents without much damage (Ho and Newman, 2003).

2.5.3 Pulse duration and pulse interval

Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Metal removal is directly proportional to the amount of energy applied during the on-time (Singh et al, 2005). This energy is controlled by the peak amperage and the length of the on-time. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. With longer pulse duration, more workpiece material will be melted away. The resulting crater will be broader and deeper than a crater produced by a shorter pulse duration. These large craters will create a rougher surface finish. Extended pulse duration also allow more heat to sink into the workpiece and spread, which means the recast layer will be larger and the heat affected zone will be deeper.

However, excessive pulse duration can be counter-productive. When the optimum pulse duration for each electrode-work material combination is exceeded, material removal rate starts to decrease. A long duration can also put the electrode into a no-wear situation. Once that point is reached, increasing the duration further causes the electrode to grow from plating build-up. The cycle is completed when sufficient pulse interval is allowed before the start of the next cycle. Pulse interval will affect the speed and stability of the cut. In theory, the shorter the interval, the faster will be the machining operation. But if the interval is too short, the ejected workpiece material will not be swept away by the flow of the dielectric and the fluid will not be deionized. This will cause the next spark to be unstable. Unstable conditions cause erratic cycling and retraction of the advancing servo. This slows down cutting more than long, stable off-times. At the same time, pulse interval must be greater than the deionization time to prevent continued sparking at one point (Fuller, 1996). Modern power supplies allow independent setting of pulse on-times and off-times. Typical ranges are from 2 to 1000µs. In ideal conditions, each pulse creates a spark. However, it has been observed practically that many pulses fail if duration and interval are not properly set, causing a loss of the machining efficiency. Such pulses are known as “open pulses”.

2.5.4 Polarity

The polarity of the electrode can be either positive or negative. The current passing through the gap creates high temperatures causing material evaporation at both electrode spots. The plasma channel is composed of ion and electron flows. As the electron processes (mass smaller than anions) show quicker reaction, the anode material